Management of Blunt Chest Trauma

Jared Griffard, MD, Lisa M. Kodadek, MD, FACS*

KEYWORDS

• Chest trauma • Blunt trauma • Thoracic injury • Rib fractures

KEY POINTS

- Blunt thoracic injury commonly includes rib fractures, sternal fracture, pneumothorax, hemothorax, and pulmonary contusions. Treatment is generally supportive with multimodal analgesia with or without tube thoracostomy.
- Tube thoracostomy may be safely deferred in patients with normal hemodynamics and simple pneumothorax less than or equal to 35 mm diameter on computed tomography imaging.
- Retained hemothorax should be treated early with video-assisted thoracoscopic surgery within 4 days of injury to reduce infectious complications and hospital length of stay.
- Extracorporeal membrane oxygenation may be safely and effectively used in select patients with blunt thoracic trauma and refractory hypoxia.
- Tracheobronchial injury, esophageal injury, diaphragmatic injury, blunt cardiac injury, and blunt aortic injury are less commonly seen after blunt thoracic trauma, but operative intervention is more frequently required.

INTRODUCTION

Blunt chest trauma constitutes a heterogeneous group of injuries and accounts for at least 10% of all hospital admissions for injury.[1] The most common mechanism leading to blunt chest trauma is motor vehicle collision (MVC), although ground-level falls are more common in older adults.[2] Blunt chest wall trauma carries a mortality of up to 25%,[3–5] and numerous injuries occurring in the thorax are life-threatening.[6]

Rib Fractures

Rib fractures may be categorized as simple, wedge, or complex fractures and are nondisplaced, offset, or displaced; ribs four through ten in the anterolateral region are most commonly injured.[7–9] Three or more contiguous ribs fractured in at least two locations are defined as a flail segment; paradoxical movement inward with respiration

Division of General Surgery, Trauma and Surgical Critical Care, Department of Surgery, Yale School of Medicine, 330 Cedar Street, Boardman Building 310, New Haven, CT 06510, USA
* Corresponding author.
E-mail address: lisa.kodadek@yale.edu

Surg Clin N Am 104 (2024) 343–354
https://doi.org/10.1016/j.suc.2023.09.007
surgical.theclinics.com
0039-6109/24/© 2023 Elsevier Inc. All rights reserved.

SHOUT
SHARE
IT

and outward with expiration is clinical flail chest.[10] Flail chest impedes thoracic expansion, decreases vital capacity, and is associated with significant underlying lung contusions. Flail segments are associated with extensive injuries and a mortality rate of 10% to 40%[11]; concomitant pulmonary contusions (PCs), pneumothorax, and hemothorax are common.[11,12] About 80% of patients with flail segments require intensive care unit (ICU) admission, with 60% requiring mechanical ventilation.[11]

Rib fractures can present with chest wall tenderness, ecchymosis, crepitus, or obvious deformity. Chest x-ray (CXR) diagnoses rib fractures with high specificity (84%–98%) but may miss almost 50% of fractures.[2,13] Computed tomography (CT) provides optimal sensitivity and specificity.[13,14]

Rib fracture treatment is primarily nonoperative, with multimodal pain management, respiratory therapy, and mobility as the mainstays of treatment. Incentive spirometry (IS) is recommended for patients ≥65 years old as a prognostic tool to determine the risk of pulmonary complications.[15] Spirometry use in a bundled protocol has been shown to reduce complications in all age groups.[16]

Multimodal analgesia is primarily used for treatment of pain associated with rib fractures.[17] Scheduled acetaminophen is well-tolerated with minimal side effects[18,19] and reaches peak effect within 1 hour.[20] non-steroidal anti-inflammatory drugs (NSAIDs) are used as an adjunct to acetaminophen.[21] Ketorolac decreases pneumonia risk and increases rate of ventilator-free and ICU-free days[22] without increasing rates of bleeding or acute kidney injury.[23] Intravenous (IV) ibuprofen and/or low-dose ketamine infusions may decrease overall narcotic use.[24,25] Opioids are effective but have unfavorable side effects: constipation, respiratory depression, somnolence, and addictive capacity. Prior opioid exposure significantly alters the treatment trajectory: opioid-naïve patients were prescribed a median of 16 days versus 36 days of treatment for those with prior opioid exposure.[26] The use of gabapentin for pain management is not strongly supported by evidence.[27]

Locoregional pain management is an important adjunct for treatment of rib fractures. Epidural catheters lead to lower subjective pain scores[28] and are conditionally recommended by the Eastern Association for the Surgery of Trauma (EAST).[29] In older patients, epidural catheters improved pain scores and are recommended.[30] Other locoregional pain management methods include serratus anterior blocks, paravertebral blocks, targeted intercostal nerve blocks, and erector spinae blocks. Paravertebral blocks can provide continuous analgesia and are non-inferior to epidural catheters.[28] Delirium in patients ≥65 years was decreased with regional analgesia in a multicenter cohort study.[31]

Consensus guidelines recommend surgical stabilization of rib fractures (SSRF) for patients with a flail segment.[30,32–34] SSRF can allow for better excursion of the chest wall, increased inspiratory volume[35] and increased lung volumes.[36] SSRF decreases mortality and is associated with improved outcomes including decreased need for tracheostomy.[30,32] Data suggest only minimal benefit in older patients.[37,38] The NON-FLAIL study showed decreased pain scores through 8 weeks of follow-up with reduced narcotic use after SSRF.[33]

Sternal Fractures

Sternal fracture (SF) occurs in 2% of patients with blunt trauma and 3.7% of patients injured in MVCs.[39,40] Only 22% to 26% of SFs are isolated; most have associated thoracic injuries.[41,42] SF can present with focal tenderness over the sternum or anterior chest wall ecchymosis.[6] CXR lacks specificity, with 81% to 93% of SFs visualized on CT only.[40,43] Bedside ultrasonography, while user-dependent, can also diagnose SFs.[43,44]

SFs are managed with multimodal analgesia, respiratory therapy, and early mobility. Despite the lack of strong supporting evidence, IS is often used as part of a bundled care set.[18,45] Operative fixation is used for unstable fractures, fracture displacement, respiratory insufficiency, and uncontrolled severe pain.[42,46] Sternal fixation improves pain scores with decreased opioid requirements, but long-term data are lacking.[46–48]

Pneumothorax

Pneumothorax, diagnosed in 40% to 50% of all patients with thoracic trauma, occurs when air accumulates between the parietal and visceral pleura.[49,50] Pneumothorax may be categorized as simple, open, tension, or occult. Simple pneumothoraces are secondary to lung parenchymal injury. Open pneumothoraces are contiguous with the atmosphere via wounds. In tension pneumothorax, air accumulates to pressures higher than atmospheric pressure with subsequent circulatory collapse from lack of venous return. Occult pneumothorax, a pneumothorax not clinically suspected or visualized on CXR but identified on CT scan, occurs in 22% of patients after blunt trauma.[2]

Signs of pneumothorax include unilateral decreased or absent breath sounds. CXR approaches 100% specificity but can miss 50% of pneumothoraces when compared with chest ultrasonography.[51] Ultrasonography is 91% to 99% sensitive; the absence of B-lines and lung sliding have a negative predictive value of 98% to 100%.[50,51] CT scan remains the gold standard for diagnosis. Large pneumothorax is defined as greater than 2 cm and greater than 3 cm by the British Thoracic Society and the American Thoracic Society, respectively.[2,52]

Pneumothorax is treated with tube thoracostomy to re-expand the lung and restore negative intrathoracic pressure.[6] Thoracostomy carries a complication rate of 19%; observation is safe for pneumothoraces $\leq$35 mm in diameter between visceral and parietal pleura on CT.[53–56] Observation of occult pneumothoraces with positive pressure ventilation is safe in hemodynamically normal patients.[57,58] Western Trauma Association (WTA) recommends tube thoracostomy for pneumothoraces greater than 35 mm on CT scan or greater than 20% on CXR in hemodynamically stable patients; thoracostomy tube is recommended regardless of size in hemodynamically unstable patients.[49] EAST and WTA recommend prophylactic antibiotics for thoracostomy to reduce the rate of empyema and pneumonia.[59,60]

Hemothorax

Hemothorax results from hemorrhage of the pulmonary parenchyma, intercostal vessels, pulmonary arteries, or pulmonary veins. Hemothorax or hemopneumothorax occurs in one-third of patients with chest trauma, with incidence increasing for each rib fractured.[5,61,62] Occult hemothorax is defined as hemothorax seen only on CT scan. Delayed hemothorax is the development or progression of hemothorax post-injury.[63,64] Retained hemothorax, an inadequately drained hemothorax, increases the risk of empyema, pneumonia, and further surgical intervention.[65]

Signs of hemothorax are nonspecific: decreased breath sounds, crepitus over ribs suggesting rib fractures, chest wall ecchymosis, and respiratory insufficiency. CXR can diagnose hemothoraces with 200 to 300 mL of blood required to visualize blunting of the costophrenic angles and almost 1000 mL is required for diagnosis on supine CXR.[2] Ultrasonography can be helpful in unstable patients, with 60% sensitivity and 98% specificity when evaluating for anechoic areas in the pleural spaces.[66] CT scan can detect small amounts of blood and is the gold standard for diagnosis.

Hemothoraces are treated with drainage, often with a thoracostomy tube. Small bore tubes (eg, 14 Fr pigtail catheters) are efficacious.[61,67–69] EAST conditionally

recommends pigtail catheter usage with clinician-guided patient selection.[61] Thoracic irrigation via the thoracostomy tube, especially with ≥1000 mL, can reduce retained hemothorax rates and improve outcomes.[70–72] Occult hemothoraces can be observed, but volumes ≥300 mL and mechanical ventilation are risk factors for failure.[56] Delayed hemothorax may develop, especially in elderly patients.[63] Retained hemothorax may be treated with tissue plasminogen activator or streptokinase.[73] Thrombolytic regimens vary widely, however, and EAST conditionally recommends video-assisted thoracoscopic surgery (VATS) over thrombolysis in operative candidates.[61] If VATS is undertaken, it should be performed within 4 days of injury to reduce empyema rates and decrease hospital and ICU length of stay, ventilator days, and mortality.[61,74]

Pulmonary Contusions

PCs result from injury to lung parenchyma leading to edema and interstitial hemorrhage, with consequent loss of gas exchange, alveolar collapse, consolidation, and atelectasis.[10,75] Subsequent hypoxia is worsened by the increased shunting of blood through unventilated alveoli and decreased compliance of the lung. PCs occur in 20% to 35% of patients with blunt chest trauma and 70% are secondary to MVCs.[2,75,76] The severity of PCs can be quantified, but it does not completely explain the poor oxygenation seen in severe PC.[77] Increased CT scan utilization has led to increased incidence of PCs.[78]

Often, signs and symptoms of PCs develop hours to days post-injury as inflammation peaks ≥24 hours post-injury.[75] CXR can show moderate–severe PCs, with 73% of PCs seen on CT scan only.[78] PC treatment is supportive: supplemental oxygen, analgesia, IS, euvolemia, and observation. Severe PCs often require intubation to maintain oxygenation.[10] In refractory cases of hypoxia due to pulmonary contusions from trauma, extracorporeal membrane oxygenation (ECMO) may be considered for treatment.[79] Although patient selection is paramount, one study has shown a 74.1% survival to hospital discharge among patients requiring ECMO after blunt thoracic trauma.[80]

Tracheobronchial Injury

Tracheobronchial injuries are seen in 0.8% to 5% of injured patients.[10] Tracheobronchial injuries can present with respiratory distress and dyspnea, hoarseness, subcutaneous emphysema, pneumothorax, or hemoptysis.[81] Persistent air leak, pneumothorax, pneumomediastinum, or subcutaneous emphysema after thoracostomy tube placement should raise clinical suspicion for this diagnosis. CXR can show a "fallen lung sign" with atelectasis of the ipsilateral lung, absent hilum, and falling away of the lung toward the diaphragm. Chest CT scans can detect obvious disruptions, but the gold standard for diagnosis is bronchoscopy.[10,82]

Tracheobronchial injuries are treated operatively, with tracheal repair performed with absorbable sutures; simple lacerations can be repaired primarily, but extensive injuries often require debridement of necrotic tissue.[10] Lateral dissection is minimized to preserve blood supply for the trachea in the 3 and 9 o'clock positions. Repairs are buttressed with vascularized flaps of strap or intercostal muscles, pericardium, or pleura. Covered metal self-expanding tracheal stents are an efficacious alternative for poor surgical candidates.[82]

Esophageal Injury

Esophageal injury (EI) is rare (≤1% in blunt chest trauma) but carries a 9.8% mortality rate.[83] Signs of EI can include subcutaneous cervical air, hemoptysis, hoarseness, or

neck hematoma. Fever, erythema, swelling, or airway distress can occur as mediastinitis develops. Contrast esophagography is the most useful diagnostic modality. CT esophagography can be used when fluoroscopy is unavailable with similar sensitivity and specificity.[84] When combined with contrast studies, diagnostic sensitivity of esophagoscopy approaches 90% to 100%.[84]

Broad spectrum antibiotics are initiated once EI is suspected.[85] Nonoperative management is indicated for hemodynamically stable patients with either a contained perforation or no contrast extravasation. Endoscopic interventions include endoscopic clipping, with 59% to 83% success, and covered esophageal stents.[85,86] Surgical management of EIs includes wide drainage with debridement of nonviable tissue and a two-layer closure with a vascularized tissue flap buttressing the repair; large esophageal perforations require esophageal diversion with end esophagostomy and distal enteral access placement.[10]

Diaphragmatic Injury

Traumatic diaphragmatic injury (TDI) incidence rate is 0.8% to 8%.[87] Most TDIs are initially asymptomatic or have nonspecific symptoms and most occur on the left. CXR has 27% to 62% sensitivity for left TDIs and 17% for right TDIs without visceral herniation.[88] CT scans are more sensitive (80%) and specific (98%) in detecting TDIs.[87] The gold standard for diagnosis is either open or minimally invasive surgical exploration.[88]

The treatment for TDIs is surgical: EAST conditionally recommends an abdominal approach for repair versus a thoracic approach, with laparoscopy considered for hemodynamically stable patients.[87,88]

Blunt Cardiac Injury

Blunt cardiac injury (BCI) is diagnosed in $\geq$70% of patients with high force blunt chest trauma.[89] BCI symptoms may be clinically absent and can develop over hours to days post-injury. Normal electrocardiogram (EKG) and troponin I levels rule out BCI.[89,90] A new right bundle branch block is the most common EKG abnormality.[91] High-sensitivity troponin T levels greater than 14 ng/L have been shown to correlate with worse outcomes.[92] Echocardiography is recommended in the presence of other abnormalities to provide diagnostic imaging and functional evaluation.[93] Transesophageal echocardiography may have higher specificity without obscured images from subcutaneous emphysema or hematomas.[94]

Most patients can be observed with admission and telemetry, but anatomic injuries warrant surgical evaluation to determine necessity of surgical repair. Arrhythmias may require pharmacologic intervention, and possibly, cardioversion and symptomatic heart block may require a pacemaker.[91,95]

Blunt Thoracic Aortic Injury

Blunt thoracic aortic injury (BTAI) can present with hemodynamic instability or nonspecific complaints: chest pain, interscapular pain, or difficulty breathing.[96] WTA recommends evaluating for BTAI after high-force mechanism of injury.[97] CXR findings may include widened mediastinum, left hemothorax, left apical cap, and loss of aortic knob.[15] CT angiography (CTA) is the gold standard, with a sensitivity of 95% to 100% and negative predictive value of almost 100%.[98] A standard CT scan with IV contrast will often capture BTAI, but a formal CTA is recommended if the diagnosis is uncertain.

Medical management of BTAI includes anti-impulse therapy with short-acting beta blockade with a goal of less than 100 mgHg systolic blood pressure and less than 100

BPM heart rate; calcium channel blockade can be added or used in place of beta-blockade. Grades I and II injuries can be managed medically with repeat CTA to assess stability.[96,97] Grades III and IV injuries should undergo surgical intervention, but Grade III injuries can be delayed safely for 48 to 72 hours if there are severe concomitant injuries. Endovascular repair is recommended due to its lower rates of morbidity and mortality.[98] Postoperative surveillance imaging is recommended, but ideal timing and length of surveillance are not established.[97]

CLINICS CARE POINTS

- Multimodal analgesia options for treatment of rib fractures may include acetaminophen, NSAIDs, ketamine infusion, epidural catheters, and locoregional pain management methods.
- Three or more contiguous ribs fractured in at least two locations are defined as a flail segment. Surgical stabilization of rib fractures may benefit select patient populations.
- Tube thoracostomy may be safely deferred in patients with normal hemodynamics and simple pneumothorax less than or equal to 35 mm diameter on computed tomography imaging.
- Prophylactic use of antibiotics for tube thoracostomy decreases the rate of pneumonia and empyema.
- Retained hemothorax should be treated early with video-assisted thoracoscopic surgery within 4 days of injury to reduce infectious complications and hospital length of stay.
- Extracorporeal membrane oxygenation may be safely and effectively used in select patients with blunt thoracic trauma and refractory hypoxia.
- Tracheobronchial injuries are diagnosed with bronchoscopy and treated operatively, with tracheal repair performed with absorbable sutures.
- A normal troponin I level along with a normal EKG rules out blunt cardiac injury.
- The initial management of blunt thoracic aortic injury include anti-impulse therapy with beta blockade.

AUTHORSHIP

Both authors meet authorship criteria as established by the International Committee on Medical Journal Editors' (ICMJE) Criteria.

DISCLOSURE

The authors have nothing to disclose.

REFERENCES

1. Dennis BM, Bellister SA, Guillamondegui OD. Thoracic Trauma. Surg Clin North Am 2017;97(5):1047–64.
2. Polireddy K, Hoff C, Kinger NP, et al. Blunt thoracic trauma: role of chest radiography and comparison with CT - findings and literature review. Emerg Radiol 2022;29(4):743–55.
3. Battle CE, Hutchings H, Evans PA. Risk factors that predict mortality in patients with blunt chest wall trauma: a systematic review and meta-analysis. Injury 2012;43(1):8–17.

4. Khandhar SJ, Johnson SB, Calhoon JH. Overview of thoracic trauma in the United States. Thorac Surg Clin 2007;17(1):1–9.
5. Lin FC, Li R, Tung Y, et al. Morbidity, mortality, associated injuries, and management of traumatic rib fractures. J Chin Med Assoc 2016;79(6):329–34.
6. American College of Surgeons. Advanced trauma life support: student manual. 10th edition. Chicago, IL: American College of Surgeons; 2018.
7. Bhavnagri SJ, Mohammed TL. When and how to image a suspected broken rib. Cleve Clin J Med 2009;76(5):309–14.
8. Harden A, Kang YS, Agnew A. Rib Fractures: Validation of an Interdisciplinary Classification System. Forensic Anthropology 2019;2(3):158–67.
9. Edwards JG, Clarke P, Pieracci FM, et al. Taxonomy of multiple rib fractures: Results of the chest wall injury society international consensus survey. J Trauma Acute Care Surg 2020;88(2):e40–5.
10. Feliciano DV MK, Moore EE. Trauma. 9th edition. New York, USA: McGraw Hill; 2020.
11. Dehghan N, de Mestral C, McKee MD, et al. Flail chest injuries: a review of outcomes and treatment practices from the National Trauma Data Bank. J Trauma Acute Care Surg 2014;76(2):462–8.
12. Getz P, Mommsen P, Clausen J, et al. Limited Influence of Flail Chest in Patients With Blunt Thoracic Trauma - A Matched-pair Analysis. In Vivo 2019;33(1):133–9.
13. Langdorf MI, Medak AJ, Hendey GW, et al. Prevalence and Clinical Import of Thoracic Injury Identified by Chest Computed Tomography but Not Chest Radiography in Blunt Trauma: Multicenter Prospective Cohort Study. Ann Emerg Med 2015;66(6):589–600.
14. Chapman BC, Overbey DM, Tesfalidet F, et al. Clinical Utility of Chest Computed Tomography in Patients with Rib Fractures CT Chest and Rib Fractures. Arch Trauma Res 2016;5(4):e37070.
15. Mukherjee K, Schubl SD, Tominaga G, et al. Non-surgical management and analgesia strategies for older adults with multiple rib fractures: A systematic review, meta-analysis, and practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2023;94(3):398–407.
16. Martin TJ, Eltorai AS, Dunn R, et al. Clinical management of rib fractures and methods for prevention of pulmonary complications: A review. Injury 2019;50(6):1159–65.
17. Rogers FB, Larson NJ, Rhone A, et al. Comprehensive Review of Current Pain Management in Rib Fractures With Practical Guidelines for Clinicians. J Intensive Care Med 2023;38(4):327–39.
18. Witt CE, Bulger EM. Comprehensive approach to the management of the patient with multiple rib fractures: a review and introduction of a bundled rib fracture management protocol. Trauma Surg Acute Care Open 2017;2(1):e000064.
19. Wei S, Green C, Truong V, et al. Implementation of a multi-modal pain regimen to decrease inpatient opioid exposure after injury. Am J Surg 2019;218(6):1122–7.
20. Ayoub SS. Paracetamol (acetaminophen): A familiar drug with an unexplained mechanism of action. Temperature (Austin) 2021;8(4):351–71.
21. Harvin JA, Albarado R, Truong V, et al. Multi-Modal Analgesic Strategy for Trauma: A Pragmatic Randomized Clinical Trial. J Am Coll Surg 2021;232(3):241–51.e3.
22. Yang Y, Young JB, Schermer CR, et al. Use of ketorolac is associated with decreased pneumonia following rib fractures. Am J Surg 2014;207(4):566–72.

23. Torabi J, Kaban JM, Lewis E, et al. Ketorolac Use for Pain Management in Trauma Patients With Rib Fractures Does not Increase of Acute Kidney Injury or Incidence of Bleeding. Am Surg 2021;87(5):790–5.
24. Bayouth L, Safcsak K, Cheatham ML, et al. Early Intravenous Ibuprofen Decreases Narcotic Requirement and Length of Stay after Traumatic Rib Fracture. Am Surg 2013;79(11):1207–12.
25. Carver TW, Kugler NW, Juul J, et al. Ketamine infusion for pain control in adult patients with multiple rib fractures: Results of a randomized control trial. J Trauma Acute Care Surg 2019;86(2):181–8.
26. Dalton MK, Chaudhary MA, Andriotti T, et al. Patterns and predictors of opioid prescribing and use after rib fractures. Surgery 2020;168(4):684–9.
27. Moskowitz EE, Garabedian L, Hardin K, et al. A double-blind, randomized controlled trial of gabapentin vs. placebo for acute pain management in critically ill patients with rib fractures. Injury 2018;49(9):1693–8.
28. Peek J, Smeeing DPJ, Hietbrink F, Hietbrink F, et al. Comparison of analgesic interventions for traumatic rib fractures: a systematic review and meta-analysis. Eur J Trauma Emerg Surg 2019;45(4):597–622.
29. Galvagno SM, Smith CE, Varon AJ, et al. Pain management for blunt thoracic trauma: A joint practice management guideline from the Eastern Association for the Surgery of Trauma and Trauma Anesthesiology Society. J Trauma Acute Care Surg 2016;81(5):936–51.
30. Brasel KJ, Moore EE, Albrecht RA, et al. Western Trauma Association Critical Decisions in Trauma: Management of rib fractures. J Trauma Acute Care Surg 2017;82(1):200–3.
31. O'Connell KM, Patel KV, Powelson E, et al. Use of regional analgesia and risk of delirium in older adults with multiple rib fractures: An Eastern Association for the Surgery of Trauma multicenter study. J Trauma Acute Care Surg 2021;91(2):265–71.
32. Kasotakis G, Hasenboehler EA, Streib EW, et al. Operative fixation of rib fractures after blunt trauma: A practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2017;82(3):618–26.
33. Pieracci FM, Leasia K, Bauman Z, et al. A multicenter, prospective, controlled clinical trial of surgical stabilization of rib fractures in patients with severe, nonflail fracture patterns (Chest Wall Injury Society NONFLAIL). J Trauma Acute Care Surg 2020;88(2):249–57.
34. Sawyer E, Wullschleger M, Muller N, et al. Surgical Rib Fixation of Multiple Rib Fractures and Flail Chest: A Systematic Review and Meta-analysis. J Surg Res 2022;276:221–34.
35. Prins JTH, Van Lieshout EMM, Overtoom HCG, et al. Long-term pulmonary function, thoracic pain, and quality of life in patients with one or more rib fractures. J Trauma Acute Care Surg 2021;91(6):923–31.
36. Campbell D, Arnold N, Wake E, et al. Three-dimensional volume-rendered computed tomography application for follow-up fracture healing and volume measurements pre-surgical rib fixation and post-surgical rib fixation. J Trauma Acute Care Surg 2021;91(6):961–5.
37. Hoepelman RJ, Beeres FJP, Heng M, et al. Rib fractures in the elderly population: a systematic review. Arch Orthop Trauma Surg 2022;143(2):887–93.
38. Chen Zhu R, de Roulet A, Ogami T, et al. Rib fixation in geriatric trauma: Mortality benefits for the most vulnerable patients. J Trauma Acute Care Surg 2020;89(1):103–10.

39. Yeh DD, Hwabejire JO, DeMoya MA, et al. Sternal fracture–an analysis of the National Trauma Data Bank. J Surg Res 2014;186(1):39–43.
40. Perez MR, Rodriguez RM, Baumann BM, et al. Sternal fracture in the age of panscan. Injury 2015;46(7):1324.
41. Doyle JE, Diaz-Gutierrez I. Traumatic sternal fractures: a narrative review. Mediastinum 2021;5:34.
42. Klei DS, de Jong MB, Oner FC, et al. Current treatment and outcomes of traumatic sternal fractures-a systematic review. Int Orthop 2019;43(6):1455–64.
43. Schellenberg M, Inaba K, Bardes JM, et al. The combined utility of extended focused assessment with sonography for trauma and chest x-ray in blunt thoracic trauma. J Trauma Acute Care Surg 2018;85(1):113–7.
44. Racine S, Drake D. BET 3: Bedside ultrasound for the diagnosis of sternal fracture. Emerg Med J 2015;32(12):971–2.
45. Macheel C, Reicks P, Sybrant C, et al. Clinical Decision Support Intervention for Rib Fracture Treatment. J Am Coll Surg 2020;231(2):249–256 e2.
46. Bauman ZM, Todd SJ, Raposo-Hadley A, et al. Impact of sternal fixation on patient outcomes: A case matched review. J Trauma Acute Care Surg 2023;94(4):573–7.
47. Harston A, Roberts C. Fixation of sternal fractures: a systematic review. J Trauma 2011;71(6):1875–9.
48. Bauman ZM, Yanala U, Waibel BH, et al. Sternal fixation for isolated traumatic sternal fractures improves pain and upper extremity range of motion. Eur J Trauma Emerg Surg 2022;48(1):225–30.
49. de Moya M, Brasel KJ, Brown CVR, et al. Evaluation and management of traumatic pneumothorax: A Western Trauma Association critical decisions algorithm. J Trauma Acute Care Surg 2022;92(1):103–7.
50. Tran J, Haussner W, Shah K. Traumatic Pneumothorax: A Review of Current Diagnostic Practices And Evolving Management. J Emerg Med 2021;61(5):517–28.
51. Chan KK, Joo DA, McRae AD, et al. Chest ultrasonography versus supine chest radiography for diagnosis of pneumothorax in trauma patients in the emergency department. Cochrane Database Syst Rev 2020;7(7):CD013031.
52. Citak N, Ozdemir S. Which pneumothorax volume/size measurement method can best predict surgical indication in primary spontaneous pneumothorax patients? A comparison of six different methods. Gen Thorac Cardiovasc Surg 2022;70(10):871–9.
53. Bou Zein Eddine S, Boyle KA, Dodgion CA, et al. Observing pneumothoraces: The 35-millimeter rule is safe for both blunt and penetrating chest trauma. J Trauma Acute Care Surg 2019;86(4):557–64.
54. Walker SP, Barratt SL, Thompson J, et al. Conservative Management in Traumatic Pneumothoraces: An Observational Study. Chest 2018;153(4):946–53.
55. Beattie G, Cohan CM, Tang A, et al. Observational management of penetrating occult pneumothoraces: Outcomes and risk factors for interval tube thoracostomy placement. J Trauma Acute Care Surg 2022;92(1):177–84.
56. Gilbert RW, Fontebasso AM, Park L, et al. The management of occult hemothorax in adults with thoracic trauma: A systematic review and meta-analysis. J Trauma Acute Care Surg 2020;89(6):1225–32.
57. Brasel KJ, Stafford RE, Weigelt JA, et al. Treatment of occult pneumothoraces from blunt trauma. J Trauma 1999;46(6):987–90, discussion 990-1.
58. Kirkpatrick AW, Rizoli S, Ouellet J, et al. Occult pneumothoraces in critical care: a prospective multicenter randomized controlled trial of pleural drainage for

mechanically ventilated trauma patients with occult pneumothoraces. J Trauma Acute Care Surg 2013;74(3):747–54, discussion 754-5.
59. Ayoub F, Quirke M, Frith D. Use of prophylactic antibiotic in preventing complications for blunt and penetrating chest trauma requiring chest drain insertion: a systematic review and meta-analysis. Trauma Surg Acute Care Open 2019;4(1): e000246.
60. Freeman JJ, Asfaw SH, Vatsaas CJ, et al. Antibiotic prophylaxis for tube thoracostomy placement in trauma: a practice management guideline from the Eastern Association for the Surgery of Trauma. Trauma Surg Acute Care Open 2022;7(1):e000886.
61. Patel NJ, Dultz L, Ladhani HA, et al. Management of simple and retained hemothorax: A practice management guideline from the Eastern Association for the Surgery of Trauma. Am J Surg 2021;221(5):873–84.
62. Liman ST, Kuzucu A, Tastepe AI, et al. Chest injury due to blunt trauma. Eur J Cardio Thorac Surg 2003;23(3):374–8.
63. Choi J, Anand A, Sborov KD, et al. Complication to consider: delayed traumatic hemothorax in older adults. Trauma Surg Acute Care Open 2021;6(1):e000626.
64. Choi J, Villarreal J, Anderson W, et al. Scoping review of traumatic hemothorax: Evidence and knowledge gaps, from diagnosis to chest tube removal. Surgery 2021;170(4):1260–7.
65. Prakash PS, Moore SA, Rezende-Neto JB, et al. Predictors of retained hemothorax in trauma: Results of an Eastern Association for the Surgery of Trauma multi-institutional trial. J Trauma Acute Care Surg 2020;89(4):679–85.
66. Staub LJ, Biscaro RRM, Kaszubowski E, et al. Chest ultrasonography for the emergency diagnosis of traumatic pneumothorax and haemothorax: A systematic review and meta-analysis. Injury 2018;49(3):457–66.
67. Bauman ZM, Kulvatunyou N, Joseph B, et al. Randomized Clinical Trial of 14-French (14F) Pigtail Catheters versus 28-32F Chest Tubes in the Management of Patients with Traumatic Hemothorax and Hemopneumothorax. World J Surg 2021;45(3):880–6.
68. Kulvatunyou N, Bauman ZM, Edine SBZ, et al. The small (14 Fr) percutaneous catheter (P-CAT) versus large (28-32 Fr) open chest tube for traumatic hemothorax: A multicenter randomized clinical trial. J Trauma Acute Care Surg 2021; 91(5):809–13.
69. Beeton G, Ngatuvai M, Breeding T, et al. Outcomes of Pigtail Catheter Placement versus Chest Tube Placement in Adult Thoracic Trauma Patients: A Systematic Review and Meta-Analysis. Am Surg 2023;89(6):2743–54.
70. Crankshaw L, McNickle AG, Batra K, et al. The Volume of Thoracic Irrigation Is Associated With Length of Stay in Patients With Traumatic Hemothorax. J Surg Res 2022;279:62–71.
71. Kugler NW, Carver TW, Milia D, et al. Thoracic irrigation prevents retained hemothorax: A prospective propensity scored analysis. J Trauma Acute Care Surg 2017;83(6):1136–41.
72. Kugler NW, Carver TW, Paul JS. Thoracic irrigation prevents retained hemothorax: a pilot study. J Surg Res 2016;202(2):443–8.
73. Hendriksen BS, Kuroki MT, Armen SB, et al. Lytic Therapy for Retained Traumatic Hemothorax: A Systematic Review and Meta-analysis. Chest 2019;155(4): 805–15.
74. Ziapour B, Mostafidi E, Sadeghi-Bazargani H, et al. Timing to perform VATS for traumatic-retained hemothorax (a systematic review and meta-analysis). Eur J Trauma Emerg Surg 2020;46(2):337–46.

75. Rendeki S, Molnar TF. Pulmonary contusion. J Thorac Dis 2019;11(Suppl 2): S141–51.
76. Miller C, Stolarski A, Ata A, et al. Impact of blunt pulmonary contusion in polytrauma patients with rib fractures. Am J Surg 2019;218(1):51–5.
77. Zingg SW, Gomaa D, Blakeman TC, et al. Oxygenation and Respiratory System Compliance Associated With Pulmonary Contusion. Respir Care 2022;67(9):1100–8.
78. Rodriguez RM, Friedman B, Langdorf MI, et al. Pulmonary contusion in the pan-scan era. Injury 2016;47(5):1031–4.
79. Hamera J, Menne A. Extracorporeal Life Support for Trauma. Emerg Med Clin North Am 2023;41(1):89–100.
80. Jacobs JV, Hooft NM, Robinson BR, et al. The use of extracorporeal membrane oxygenation in blunt thoracic trauma: A study of the Extracorporeal Life Support Organization database. J Trauma Acute Care Surg 2015;79(6):1049–53.
81. Shemmeri E, Vallieres E. Blunt Tracheobronchial Trauma. Thorac Surg Clin 2018; 28(3):429–34.
82. Grewal HS, Dangayach NS, Ahmad U, et al. Treatment of Tracheobronchial Injuries: A Contemporary Review. Chest 2019;155(3):595–604.
83. Raff LA, Schinnerer EA, Maine RG, et al. Contemporary management of traumatic cervical and thoracic esophageal perforation: The results of an Eastern Association for the Surgery of Trauma multi-institutional study. J Trauma Acute Care Surg 2020;89(4):691–7.
84. Norton-Gregory AA, Kulkarni NM, O'Connor SD, et al. CT Esophagography for Evaluation of Esophageal Perforation. Radiographics 2021;41(2):447–61.
85. Khaitan PG, Famiglietti A, Watson TJ. The Etiology, Diagnosis, and Management of Esophageal Perforation. J Gastrointest Surg 2022;26(12):2606–15.
86. Schraufnagel DP, Mubashir M, Raymond DP. Non-iatrogenic esophageal trauma: a narrative review. Mediastinum 2022;6:23.
87. Reitano E, Cioffi SPB, Airoldi C, et al. Current trends in the diagnosis and management of traumatic diaphragmatic injuries: A systematic review and a diagnostic accuracy meta-analysis of blunt trauma. Injury 2022;53(11):3586–95.
88. McDonald AA, Robinson BRH, Alarcon L, et al. Evaluation and management of traumatic diaphragmatic injuries: A Practice Management Guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2018;85(1):198–207.
89. Shoar S, Hosseini FS, Naderan M, et al. Cardiac injury following blunt chest trauma: diagnosis, management, and uncertainty. Int J Burns Trauma 2021; 11(2):80–9.
90. Clancy K, Velopulos C, Bilaniuk JW, et al. Screening for blunt cardiac injury: an Eastern Association for the Surgery of Trauma practice management guideline. J Trauma Acute Care Surg 2012;73(5 Suppl 4):S301–6.
91. Nair L, Winkle B, Senanayake E. Managing blunt cardiac injury. J Cardiothorac Surg 2023;18(1):71.
92. Keskpaik T, Starkopf J, Kirsimagi U, et al. The role of elevated high-sensitivity cardiac troponin on outcomes following severe blunt chest trauma. Injury 2020;51(5): 1177–82.
93. Huis In 't Veld MA, Craft CA, Hood RE. Blunt Cardiac Trauma Review. Cardiol Clin 2018;36(1):183–91.
94. Scagliola R, Seitun S, Balbi M. Cardiac contusions in the acute care setting: Historical background, evaluation and management. Am J Emerg Med 2022;61: 152–7.

95. El-Andari R, O'Brien D, Bozso SJ, et al. Blunt cardiac trauma: a narrative review. Mediastinum 2021;5:28.
96. Mazzaccaro D, Righini P, Fancoli F, et al. Blunt Thoracic Aortic Injury. J Clin Med 2023;12(8):2903.
97. Brown CVR, de Moya M, Brasel KJ, et al. Blunt thoracic aortic injury: A Western Trauma Association critical decisions algorithm. J Trauma Acute Care Surg 2023; 94(1):113–6.
98. Davis KA. Blunt thoracic aortic injury diagnosis and management: two decades of innovation from Memphis. Trauma Surg Acute Care Open 2023;8(Suppl 1): e001084.